Feasibility and Accuracy Analysis of Input Power Estimation for Boost PFC Converters without Additional Sensors

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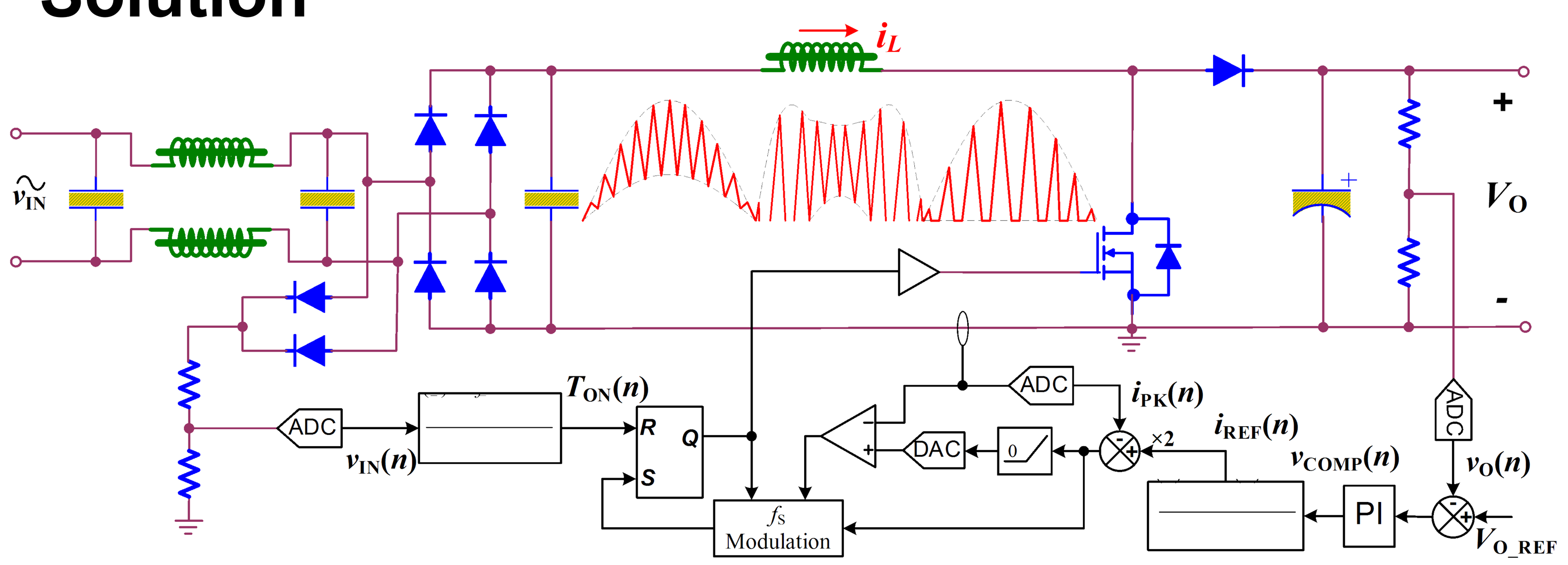
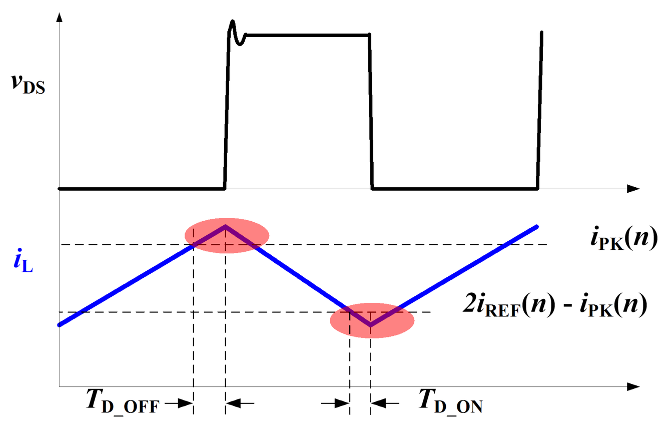
Abstract

The most commonly used boost power factor correction (PFC) converters in the industry only sample input voltage, output voltage, and inductor current, and control the switching frequency and duty cycle. This paper discusses the feasibility of estimating real-time input power based on this basic and limited information in a boost converter. The influences of major non-ideal effects, including turn-on delay, turn-off delay, and current distortion caused by the parasitic oscillation in discontinuous conduction mode (DCM), are analyzed in detail, and an algorithm for accurate estimation is proposed accordingly. In contrast to the power metering implemented by input voltage and current sensors, this study provides an approach to monitor input power without introducing any additional system complexity, cost, or power loss. A 400W prototype has been built based on the HR1211GY digital PFC and LLC combo controller, and the feasibility and the accuracy of the theoretical analysis have been validated by experimental results.

Solution



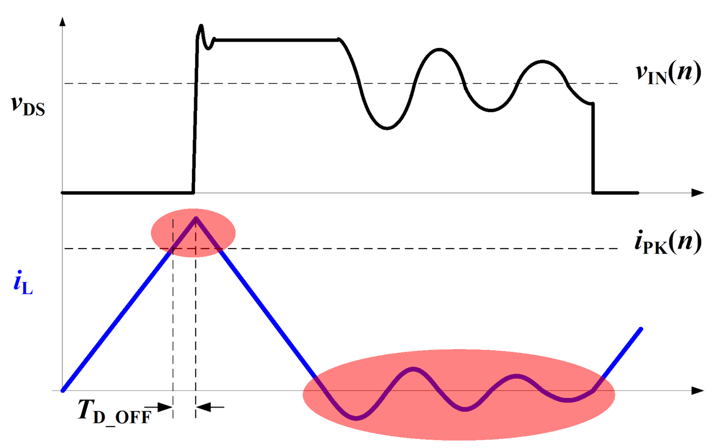


The current error in CCM

Based on the multi-mode control scheme shown above, ideally, i_{REF} can be used to calculate the input power. However, compensating for the error caused by the non-ideal effects is a key to guarantee the estimation accuracy.

In CCM, the error is mainly introduced via the turn-on delay T_{D_ON} and the turn-off delay T_{D_OFF}.

$$\left\langle \tilde{i}_{L\_CCM}(n) \right\rangle_{T_S} = \frac{v_{IN}(n) T_{D\_ON}}{2L} - \frac{[V_O - v_{IN}(n)] T_{D\_OFF}}{2L}$$

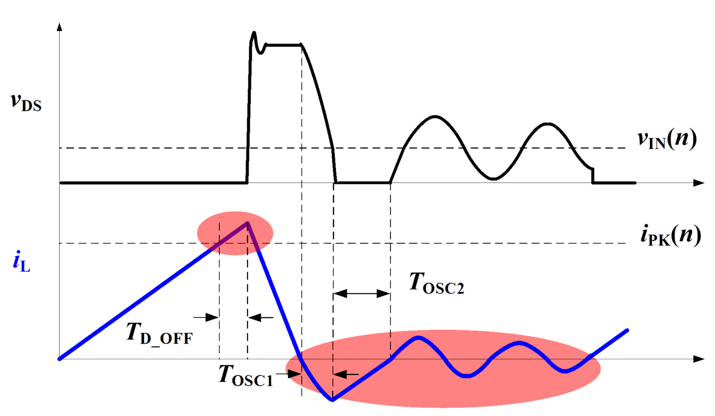


The current error in DCM, $2v_{IN}(n) \geq v_O$

In DCM, the error is mainly introduced by the turn-off delay T_{D_OFF} and the DCM oscillation. Besides, the error modeling is also different based on whether the oscillation is free or clamped by the body diode of the boost MOSFET.

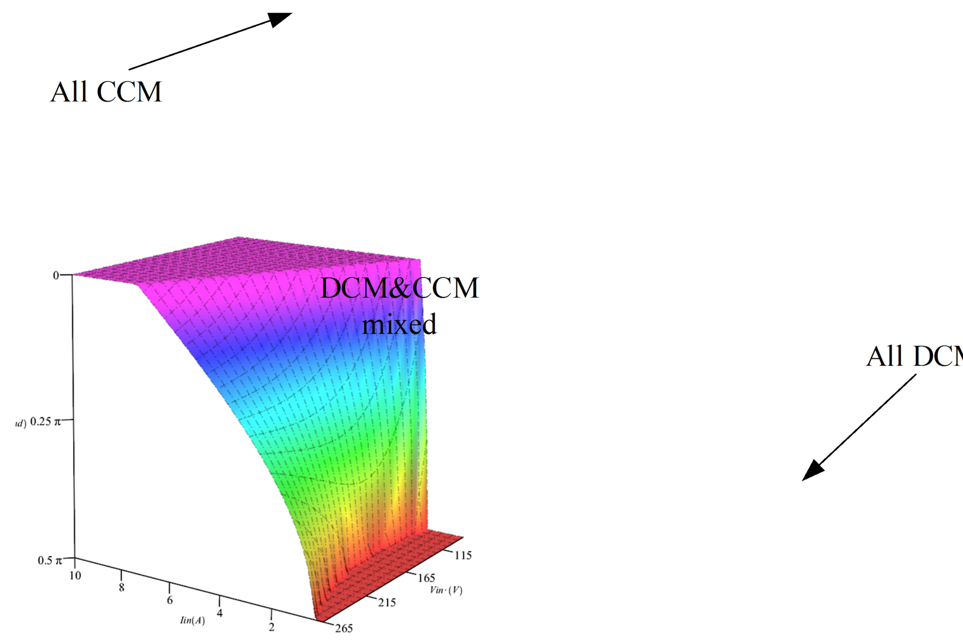
$$\left\langle \tilde{i}_{L\_DCM}(n) \right\rangle_{T_S} = \begin{cases} \left\langle \tilde{i}_{L\_DCM\_D}(n) \right\rangle_{T_S} + \left\langle \tilde{i}_{L\_DCM\_OF}(n) \right\rangle_{T_S}, & v_{IN}(n) \geq \frac{V_O}{2} \\ \left\langle \tilde{i}_{L\_DCM\_D}(n) \right\rangle_{T_S} + \left\langle \tilde{i}_{L\_DCM\_OC}(n) \right\rangle_{T_S}, & v_{IN}(n) < \frac{V_O}{2} \end{cases}$$

Where the complete equation can by found in the full paper.



The current error in DCM, $2v_{IN}(n) < v_O$

The transition angular between CCM and DCM can be deduced based on the input voltage and the reference current at the boundary conduction.



Combing all the analysis above, the active input power can be estimated as

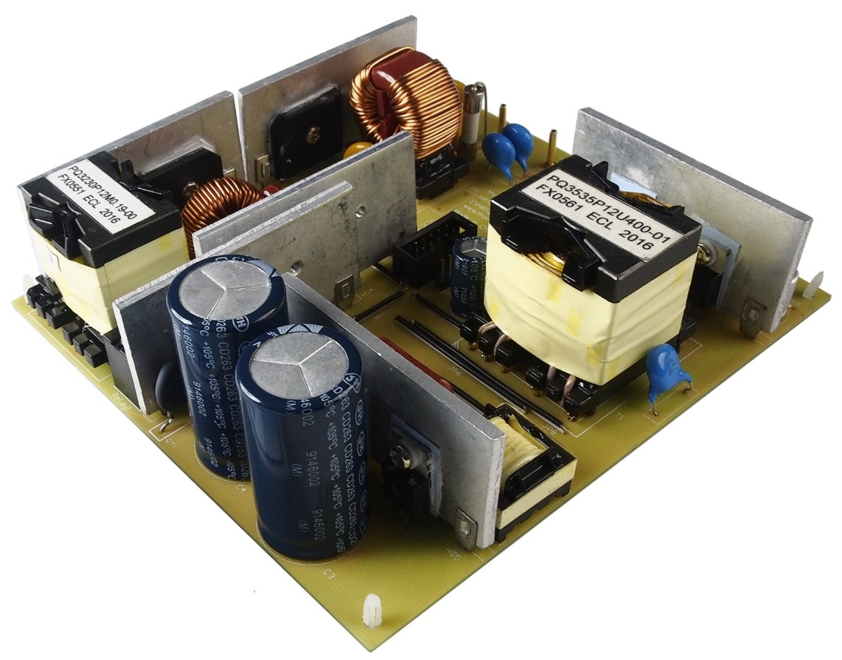
$$P_{IN} = \frac{2\omega_L}{\pi}\left[\int_0^{\frac{\pi}{2\omega_L}} v_{IN}^*(t) i_{REF}(t)dt + \int_0^{\frac{\theta_T}{\omega_L}} v_{IN}^*(t)\tilde{i}_{L\_DCM}(t)dt + \int_{\frac{\theta_T}{\omega_L}}^{\frac{\pi}{2\omega_L}} v_{IN}^*(t)\tilde{i}_{L\_CCM}(t)dt\right]$$

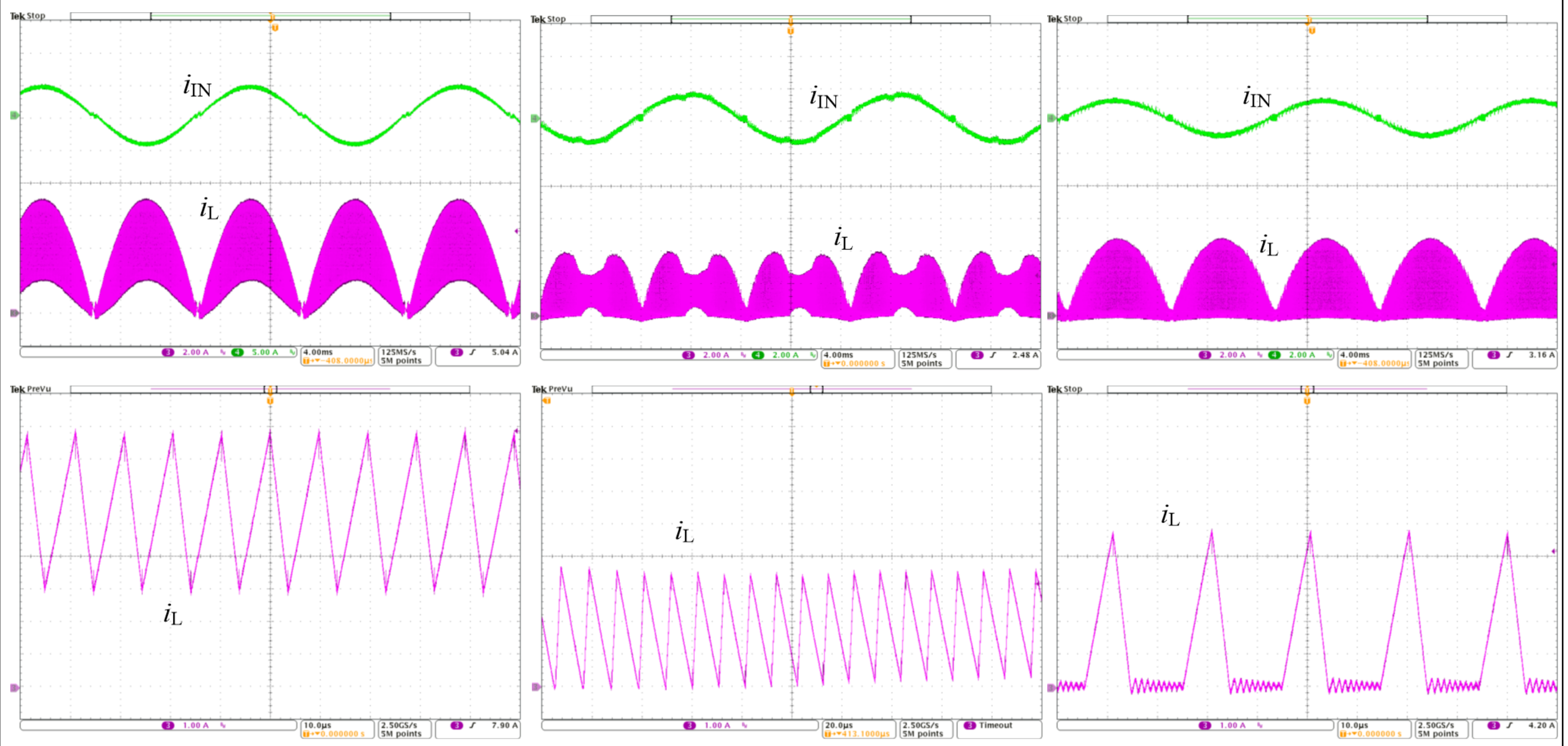
Where $v_{IN}^*(t)$ is reconstructed input voltage, considering V_{F_BD} as the forward voltage of one bridge rectifier diode and R_L is the total equivalent resistance of all the filter inductors.

$$v_{IN}^*(t) = v_{IN}(t) + R_L i_{REF}(t) + 2V_{F\_BD}$$

Results

For verification, a 400W prototype is designed and implemented based on the **HR1211GY**, a digital multi-mode PFC and LLC combo controller. The key parameters of the power supply can be programed by a user friendly GUI, and also the instant states required for the power estimation are accessible through the integrated UART interface of HR1211GY in real time.

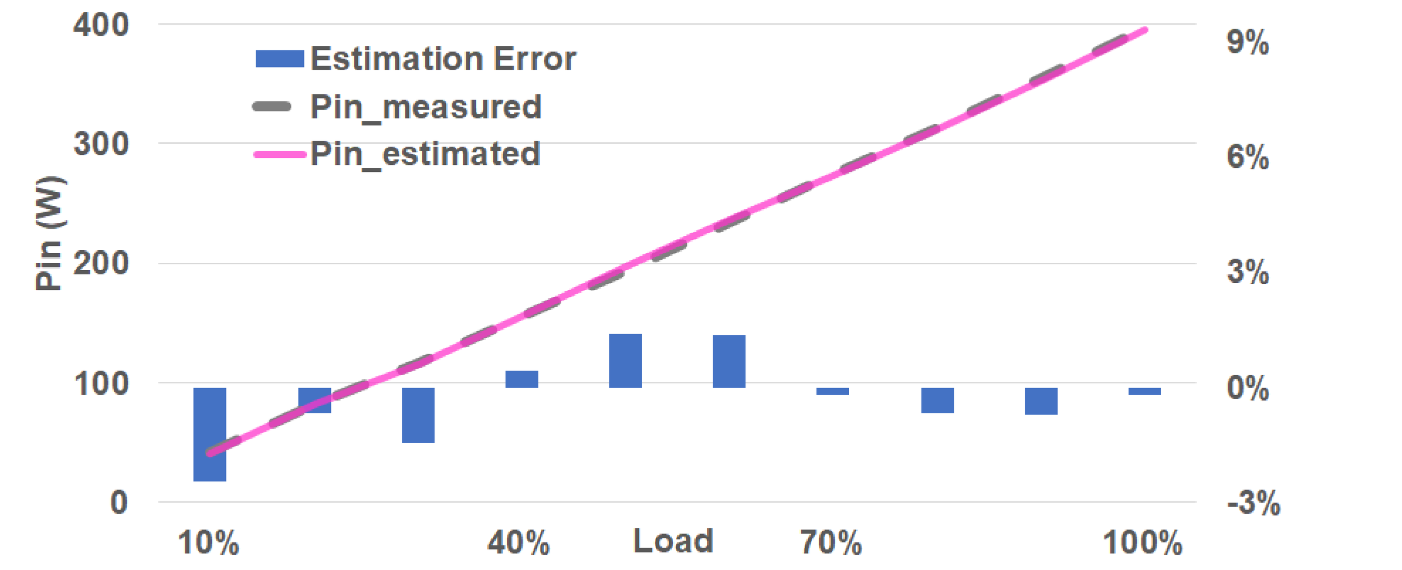




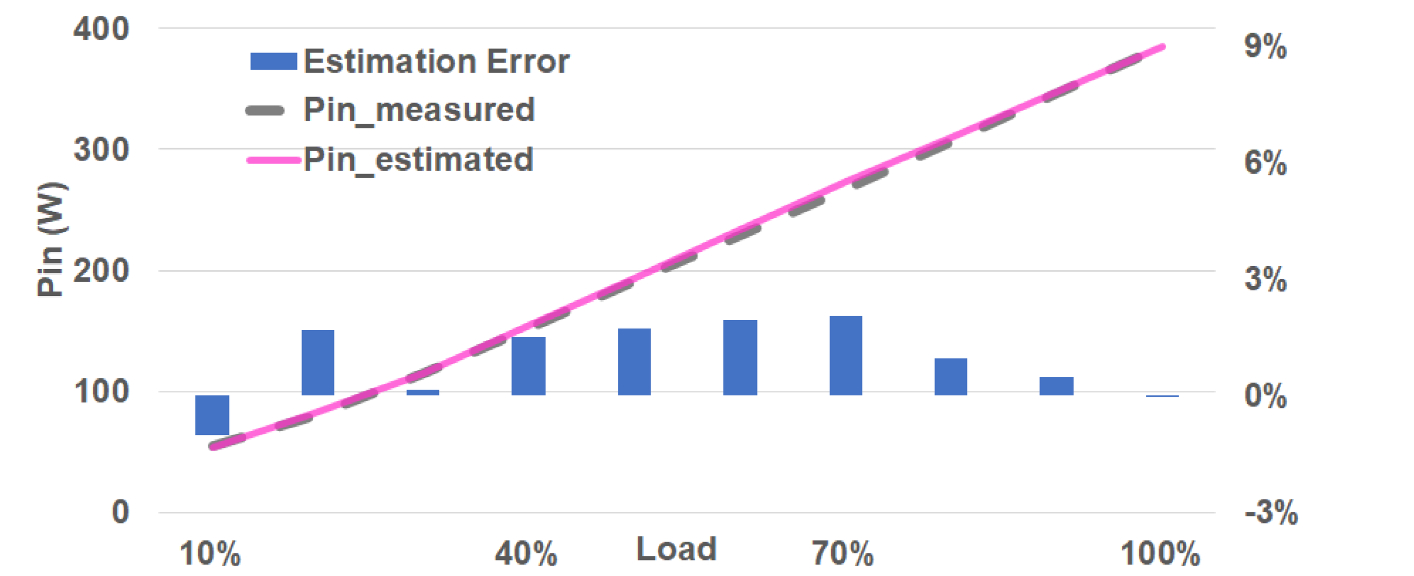
All CCM V_{IN_rms} = 110V P_O = 400W

CCM&DCM Mixed V_{IN_rms} = 230V P_O = 400W

All DCM V_{IN_rms} = 110V P_O = 100W



Contrast between the calculated and the measured input power (V_{IN_rms}=110V)



Contrast between the calculated and the measured input power (V_{IN_rms}=230V)

Conclusion

This paper studied the feasibility of implementing active input power estimation without any additional sensors for boost PFC converter. The analysis in this paper accounts for the influence of parasitic effects, such as turn-on and turn-off delays, DCM oscillation, transition between DCM and CCM, and active power loss on passive components. Based on the mathematical modeling of the system and parasitic effects, an algorithm for accurately estimating the input power has been proposed. It takes the characteristics of the mainstream multi-mode PFC control scheme into consideration, and is able to support a wide operating range. The proposed estimation approach has been verified by experimental results on a 400W boost PFC prototype based on the HR1211GY. As digital PFC controllers are becoming more and more popular in practical applications, this study provides a possible approach to reduce system complexity and cost, as well as to improve reliability for power supply products in the future, by implementing basic power metering functions without adding any additional sensors.

References

[1] D. Simonetti, J. Vieira, and G. Sousa, “Modeling of the high-power factor discontinuous boost rectifiers,” in IEEE Trans. Ind. Electron., vol.46, 1999.

[2] K. De Gusseme, D. M. V. de Sype, A. P. Van den Bossche and J. A. Melkebeek, "Sample correction for digitally controlled boost PFC converters operating in both CCM and DCM," in Proc. IEEE APEC 2003

[3] K. De Gusseme, D. M. V. de Sype, A. P. M. Van den Bossche and J. A. Melkebeek, "Digitally controlled boost power-factor-correction converters operating in both continuous and discontinuous conduction mode," in IEEE Trans. Ind. Electron., vol. 52, no. 1, pp. 88-97, Feb. 2005.

[4] …. (full reference list to be found in the paper)